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A REMOTE LABORATORY FOR MOTION CONTROL AND FEEDBACK DEVICES

SUMMARY *Remote laboratories for measurement and control represent an ever growing field in the distant teaching of engineering and technology students. The existing remote laboratories for motion control with feedback control devices are reviewed in this paper. The feasibility of a new motor feedback control web-based laboratory for e-teaching is discussed. A FPGA-based hardware solution for a universal motion control test bench, including a processing board and data acquisition board, is proposed.*

Keywords: *remote laboratories, distance education, power converters, motion control, data acquisition, feedback devices*

1.INTRODUCTION

The role of the laboratories in engineering and scientific education as an effective tool for development of students' practical skills has been

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undisputed. Their contribution to the professional development of the graduates is indispensable. The real laboratories, also called proximal or“hands-on“ laboratories, provide live interaction with the equipment and produce real experimental results under supervisor’s control. However, they are expensive to establish and operate and have limited availability.

The advancement in Internet technology has paved the way for alternatives to emerge in the form of virtual (simulated) and remote laboratories [22].

Virtual laboratories (VL) provide very good pedagogical experience by means of appropriate virtual models for simulation of processes that are hard to understand. They contribute to better understanding of complex systems and are much less expensive and have no time restrictions compared to the real laboratories. Their major disadvantages are: models are only approximations of the real processes and cannot completely substitute real experiments. VLs lack the live experience for engineering students and contribute to their practical skill development in a limited way.

In the recent ten years, with technology expansion in the areas of client-server software systems, data-acquisition hardware devices and growing speed and usage of the Internet, a new approach for distance teaching and learning has been well established. Teaching has moved from big auditoriums and laboratories at the universities to every home and internet-café in the world. Remote, distant, networked, web-based, tele-operated are hallmarks heralding a new area of engineering and science education, namely the remote laboratories (RL). Their advantages in delivering education are:

Comprehensive pedagogical and methodological structure – students are typically first presented with theoretical material, then simulations based on the topic are conducted, and finally they perform a real experiment remotely. That gives them a true understanding of complex theoretical matters and practical proficiency. Conducted surveys demonstrate that students appreciate the autonomy to learn subjects, feel motivated and consider RLs as a good tool for collaborative learning [3].

Flexible study and better time management – usually there is no need for a supervisor and limited need for supporting personnel, the remote experiment is not restricted in time and place. The automatic booking system performs an effective job for checking and registration of students in the university database as well as in time distribution of laboratory experiments.

Good economic value – there is only one initial price for the equipment and the developmental work can be done by postgraduate and undergraduate students. Since RLs allow to be shared by hundreds of students from the campus site, other universities, home or overseas, the cost of education per student is much lower compared to a real laboratory with a number of test benches and supporting staff.

Remote laboratories for measurement and control represent one of the fastest growing fields of education in engineering at universities. They are flexible, expandable and easily improvable and provide e-learners with access to often very expensive equipment at a price of a remote internet connection. In a safe and distant way students can explore processes of high voltage transmission system or industrial high power motion control. The usual structure of a distant experimental measurement and control in RL is shown in Figure 1.

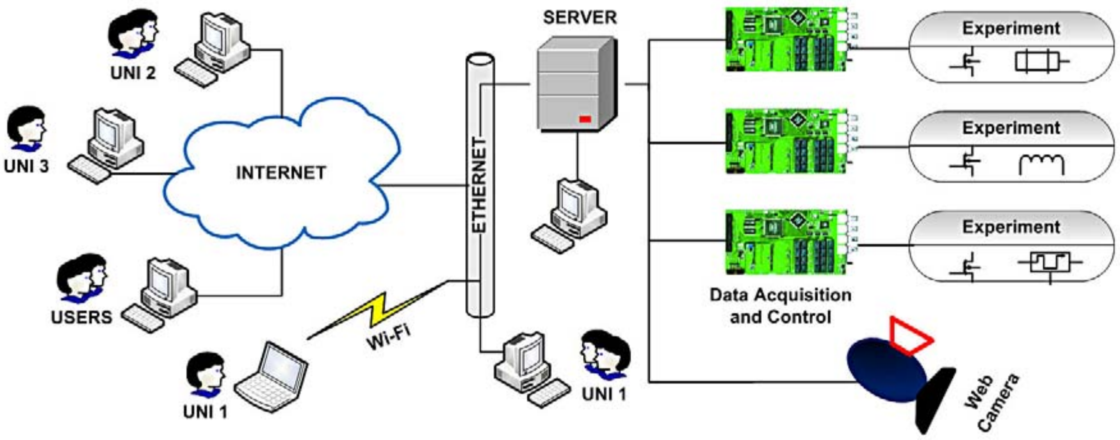


Fig. 1. Typical structure of a remote laboratory for measurement and control

Distant users can access the RL experiment through the university's Ethernet or wireless network, or through the Internet, from another university, home or even overseas. The client software provides real time virtual measuring instruments and equipment with animated buttons and knobs, thus replicating real instruments and equipment present at a host location. When started, software automatically connects to the remote server and exchanges specific information to setup the required experiment. Then the server communicates with a software control application, which applies the required signals to the experimental workbench equipment and reads the measured values in real time. Usually one or more experiments are conducted from a computer with specialised data acquisition boards, which provide a number of analogue inputs and outputs for measurement and processing of analogue signals, and also a number of digital inputs and outputs for data exchange and control. Web cameras deliver live video and sound streaming from the experimental side, thus enhancing the feeling of a real test environment.

One specific category of the discussed RL is the one for motion control. Those RLs provide teaching tools in a variety of courses in power electronics and electromotion areas.

The aim of this paper is:

- to review current literature describing RL for motion control with a special focus on experiments with feedback devices;
- to propose a hardware solution for a motion control test bench;
- to discuss the implications for future research and development of a remote laboratory.

2. LITERATURE SEARCH

Method of search – English-language literature indexed in three electronic databases (IEEE, Science Direct and Google Scholar) and reference lists were searched until May 2010 using search keywords such as ”remote laboratory”, “remote experiment”, “teleoperation”, “distant education”, “power converters”, “motion control”, “feedback devices”, “resolver’, “encoder”, “data acquisition”. Overall, more than 100 articles in the area of power electronics and electromotion laboratories were found and reviewed. In addition 55 other articles concerning RLs for measurement and control or discussing the client/server architecture were investigated. For the purposes of this paper, many articles were excluded, for example: laboratories for motion control which are not remote; RLs using industrial equipment on the test bench – CNC/PLC controllers and industrial servo drives/motors. Finally, 38 articles were selected for a full-text review as relevant to RL for motion control.

Terminology and results – A standard structure of an industrial servo control system, used in a variety of applications for motion control is shown in Figure 2. The three-phase AC mains supply is converted to DC by means

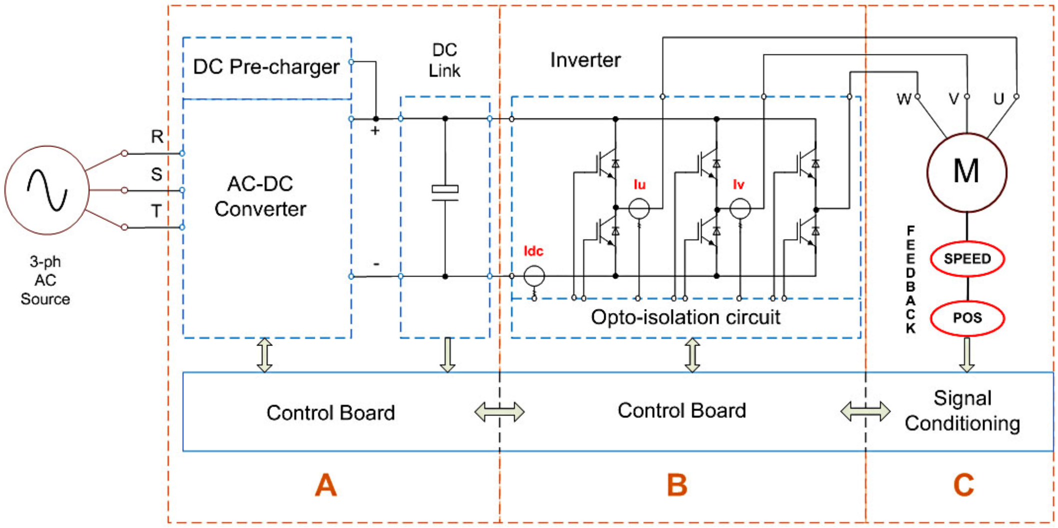
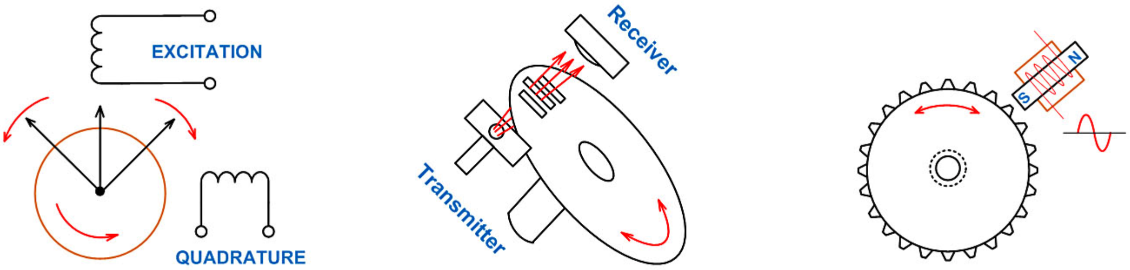


Fig. 2. Block diagram of a motion control system

of AC-DC converter. That converter typically is an unregulated or regulated rectifier, sometimes combined with a circuit for DC over-voltage control: an integrated brake chopper with a braking resistor or a regenerative inverter. In order to decrease the inrush current, normally a DC pre-charging device is implemented. The inverter is usually based on three phase full Insulated-Gate Bipolar Transistor (IGBT) bridge with gate control circuits and current sensors on the DC bus and two of the phases. It operates the motor, which is mechanically coupled with feedback devices for speed control and rotor position.

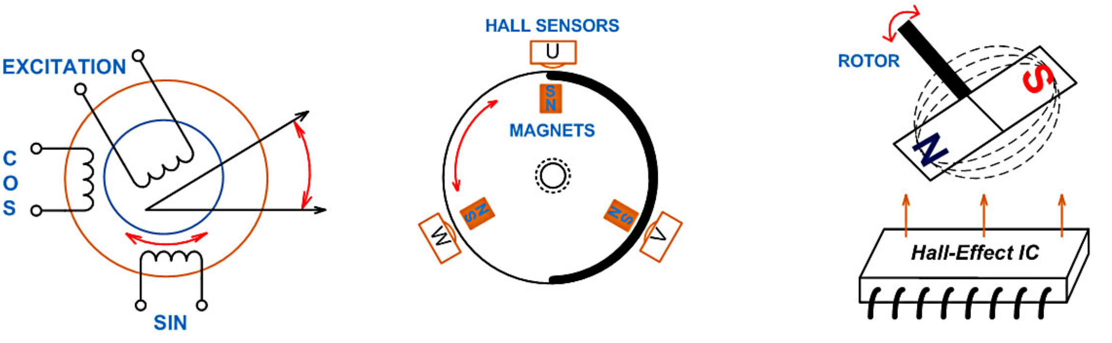
Speed control devices, presented in Figure 3, measure the rotary speed of the motor and deliver velocity into feedback loop of the motion controller. They can work by different physical principles: as electromagnetic, optical, etc.



AC TACHOGENERATOR **INCREMENTAL OPTICAL ENCODER** **MAGNETIC SPEED SENSOR**

Fig. 3. Feedback devices for speed control

Position control devices, presented in Figure 4, measure the exact angle position of the rotor and deliver position feedback for the motion controller. They work in a similar way as speed sensing devices.



RESOLVER **RLG – ROTOR POSITION EMITTER** **MAGNETIC ABSOLUTE ENCODER**

Fig. 4. Feedback devices for position control

Following the structure shown in Figure 2, reviewed papers discuss the following sections of the system:

A. ***AC-DC converter*****.** Experimentations with multilevel power converters as a platform for advanced users and postgraduate researchers are presented in [32]. A line-side converter with direct vector and synchronous current control is chosen in this application. From the advanced users menu PWM can be configured as sinusoidal, space-vector or third harmonic. The DC-bus controller, current controller and Phase-Locked Loop (PLL) can be adjusted with corresponding Proportional-Integral (PI) parameters. The following experiments are conducted: control without passive load, reactive power compensation and control with passive load.

B. ***Inverter*****.** Remote experiments as a part of the "Industrial Electronics" course are presented in [3]. They include PWM control and measurements on a full H-bridge converter for DC motor operation. Similarly, remote measurements with DC-DC buck converter and operation of a three-phase inverter with vector modulation are described in [7]. Assignments for simulation, animation and programming of microcontroller extend the teaching effectiveness of the described RL. A tele-operated Brushless DC (BLDC) motor controller is introduced in [12]. The implementation of Symmetrical PWM with Synchronous Sampling (SPSS) and the increase of current control bandwidth and reduction of PWM noise effects are explained in detail. Further, the full four-quadrant control and phase switching of the IGBT bridge are discussed. Finally, experiments with a tele-operated robot for manual driving of a nuclear fuel handling machine are performed, thus verifying the applicability of the controller. The publication [20] discusses a web-accessible direct torque controller for Permanent Magnet Synchronous Motor (PMSM). The advantage of the solution is the use of soft-CPU core in the Field Programmable Gate Array (FPGA) chip. Various experiments, performed from the client site's Java applet, verify the functionality of the controller. The theory and practice of PWM principles, as part of the "Electrical Drives and Power Electronics" course, are discussed further in [22]. It has excellent teaching qualities in terms of multimedia presentations and simulations of carrier-based PWM and space-vector modulation for two-level converters. Moreover, practical experiments with the three-phase IGBT inverter are conducted, thus confirming the simulated results with different modulations.

C. ***Motors and motion control feedback devices (MCFD)*****.** Although the majority of the reviewed papers describe some remote experiments with motors, many of them are focused on the software client/server implementation or teaching capabilities of RLs rather than technical details of the applied motor control solution. A comprehensive platform, using three test benches for control of DC, BLDC and stepper servomotors with particular attention to a DC motor servo system with controlled motor load, is demonstrated in [5]. The encoder and servomotor control signals are visually represented. An incremental optical encoder, absolute encoder, DC tachogenerator and rotor position device are used as MCFD in the experiments. [4, 8] present a tele-laboratory architecture, in particular a robotic arm control and controller for linear time-invariant systems. The control experiment uses a DC motor with incremental encoder. A teleoperation of a brushless DC motor, coupled with a resolver as a feedback device, is introduced in [12]. The use of an incremental encoder in the experimental mechatronic device is reported in [33], but no special attention is given to MCFD. An interesting solution with Embedded Ethernet Microcontroller for the remote control of a DC motor is presented in [1, 39]. An optical encoder, DC tacho-generator and potentiometer are used as feedback devices, but no dedicated experiments are conducted with them. Another DC motor control experiment, using a Gray-Code disc, DC tacho-generator and potentiometer, is described in [40]. It emphasises the software/networking development with limited hardware description.

It is worth to mention the remote laboratory for microelectronics fabrication, developed at the University of South Australia, where 18 BLDC motors with Hall sensors for position feedback are used in the remote manipulator. For their control special hardware and software solutions were developed [27]. Some other DC motor control experiments with DC tacho-generator, encoder or potentiometer as MCFD are described in [3], [10], [11], [13], [15], [24], [31] and [35].

The only works dedicated to distant experiments with MCFD are described in [37, 38]. This RL participates in “Power Electronics and Motion Control Web Laboratories” (PEMCWebLab) as part of a collaborative project amongst eleven European countries called “E-learning Distance Interactive Practical Education” (EDIPE). The papers explain the working principle of the resolver as a rotor position measuring device and the phase relationship between excitation input signal and Sin/Cos output signals. The “Calibration of resolver” practical for resolver alignment to the rotor magnets d-axis of PMSM motor is presented. Appropriate graphics represent the alignment of the current phasor and d-axis.

The literature review of the existing RL for motion control reveals a niche in research of distance e-teaching courses and experiments, focused especially on feedback control devices. A novel approach has been proposed for the development of a remote laboratory for motion control and feedback devices.

3. DESIGN CONSIDERATIONS

A proposed hardware solution for motion control test bench, utilising the stand alone motion control IC MC73110 from Performance Motion Devices (PMD), standard IGBT full-bridge inverter, BLDC and PMSM motors, a resolver and a magnetic encoder, is shown in Figure 5.

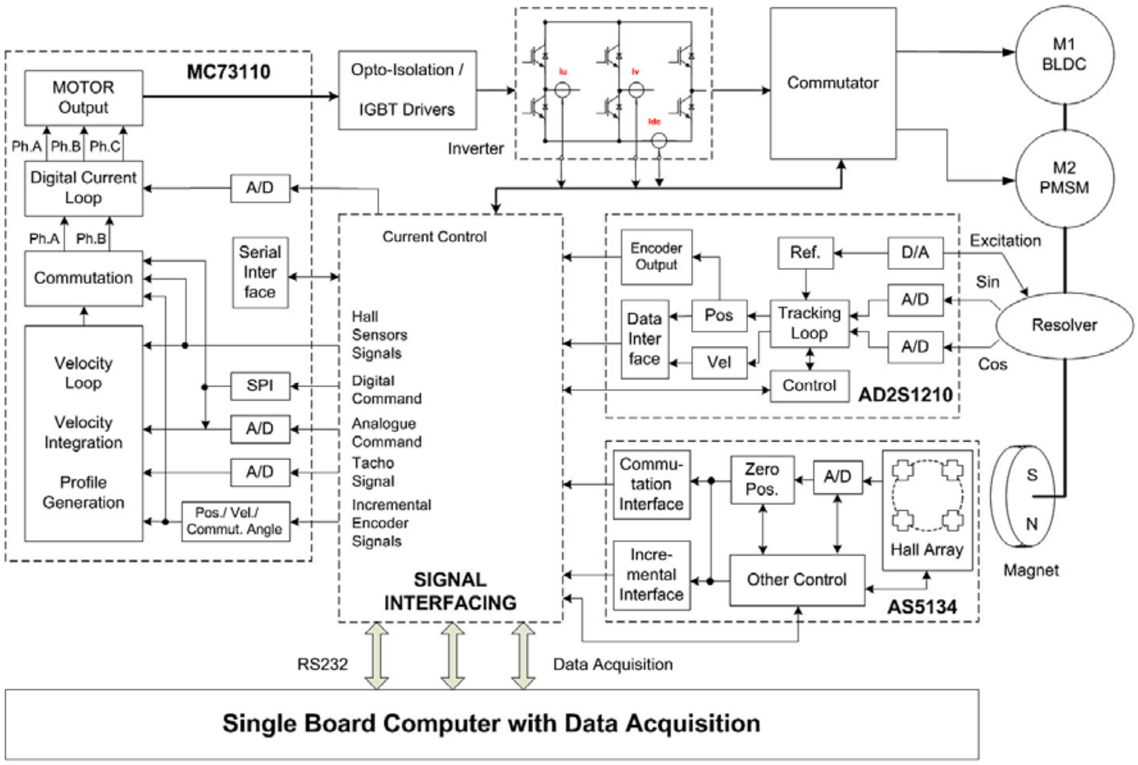


Fig. 5. Hardware solution for motion control with resolver and magnetic encoder.

It is to comprise the following hardware devices:

MC73110 – a FPGA based, high-performance motion control IC, which incorporates all the needed internal blocks to work as a stand-alone servo controller. In addition, online programming is available by means of a serial interface. For that purpose, over 130 intelligent commands are utilised. It can operate either BLCD motors (trapezoidal control) or PMSM motors (sinusoidal control) and has 3 inputs for velocity and position feedback devices – a DC tacho-generator, a Rotor Position Emitter (RLG) and an incremental encoder. Several operational modes are implemented, including Field Oriented Control (FOC).

AD2S1210 – a complete 10-bit to 16-bit resolution tracking resolver-to-digital converter, and on-board programmable sinusoidal oscillator that provides sine wave excitation for resolvers [42]. It has outputs for velocity (incremental encoder) and position (absolute position encoder).

AS5134 – a contactless magnetic rotary encoder for accurate angular measurement over a full turn of 360° [43]. It has outputs for velocity – incremental encoder and position – commutation (RLG) and absolute position encoder.

BLDC and PMSM motors, driven by full IGBT bridge, and controlled by MC73110.

Resolver and magnetic encoder as feedback devices – combined with AD2S1210 and AS5134. The following standard devices are emulated: DC tacho-generator, Hall sensor commutation or RLG, incremental encoder, absolute encoder and resolver.

Signal conditioning and interfacing board – it converts the DC level and amplitude of the signals according to the requirements of the integrated circuits, and interfaces the devices. Also it provides communication between the integrated circuits and the data acquisition board.

Single board computer – Hercules II from Diamond Systems [44]. It delivers a comprehensive solution for software and hardware control. The integrated auto-calibrating data acquisition board works at 250 kHz maximum sampling rate and has 32 analogue inputs with 16-bit resolution, 4 analogue outputs with 12-bit resolution and 40 digital programmable inputs/ outputs. Supplied are drivers for real time operating systems as QNX Neutrino and RTLinux, thus making possible to run software such as LabVIEW, MATLAB, Simulink, etc.

Based on the above hardware design, the following objectives for further development are considered:

- Establishment of a methodology for presentation of the complex theoretical material to distant learners and the development of the needed teaching and simulation models.
- Development of Virtual Instruments in LabVIEW and MATLAB environments. Development of necessary infrastructure of web server, application server and TCP/IP communication and data transfer.
- Development of a client interface and publishing the created teaching material, simulations and virtual instruments on the web. Development of a user management system and all other relevant systems.
- Tests and measurements of process speed to determine the real-time capabilities of the system and implementation of corresponding improvements.
- User testing of the Remote Laboratory and survey of the perceptions, followed by recommendations for further improvements.

4. CONCLUSION

Remote laboratories might provide a better way to use shared resources and thus reduce the overall costs to engineering education. A well-developed RL offers a real-time practical remote experimentation accompanied by teaching materials and related simulations, and becomes a valuable tool for e-learning. The current study focuses on the use of motion control and their feedback devices (MCFD) as a primary subject of distant experiments and their practical educational value for teaching engineering students. The literature review reveals that very limited research has been conducted on remote experiments with those devices, which indicates a room for further developments in this area.

The novel hardware approach for remote experiments with MCFD has the potential to extend the learning qualities in a wide range of engineering undergraduate courses. It comprises of simulation and practical experimentation leading to a better understanding of the complex processes and the theory behind the in motion control systems.

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Manuscript submitted 17.08.2010
Reviewed by Bartosz Sawicki, Ph.D., Eng.

ZDALNE LABORATORIUM KONTROLI RUCHU I URZĄDZEŃ SPRZĘŻENIA ZWROTNEGO

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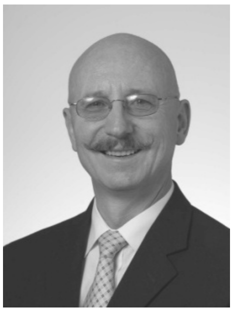
STRESZCZENIE *Zdalne laboratoria służące do pomiarów i sterowania stanowią sektor o rosnącym znaczeniu w nauczaniu na dystans studentów kierunków inżynierskich i technologicznych. Artykuł zawiera przegląd istniejących zdalnych laboratoriów służących do sterowania ruchomymi obiektami ze sprzężeniem zwrotnym. Możliwość implementacji nowego internetowego laboratorium opartego o silniki elektryczne ze sprzężeniem zwrotnym do e-nauczama, jest w centrum dyskusji. Proponowane jest rozwiązanie hadwarowe oparte o FPGA dla uniwersalnego stanowiska pomiarowego do sterowania silników elektrycznych, zawierającego układ przetwarzający i interfejs.*

Stamen GADZHANOV is a PhD student at the University of South Australia. He received his Masters degree in electrical engineering and microelectronics from Technical University of Gabrovo, Bulgaria. From 2001 to 2010 he has been working in the area of industrial automation, with main priorities in servo drive systems, CNC and PLC controllers. His current research interests are distant education and motion control.



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Özdemir GÖL is currently an Associate Professor of Electrical Engineering at the University of South Australia in Adelaide. He holds MSc., ME and PhD degrees, all in electrical engineering. His experience includes industrial and academic assignments in Turkey, Switzerland, Belgium, France, Finland and Greece. His research interests include electrical machines and engineering education.